DETERMINATION OF SIZE OF SERVICE OR SECONDARY CONDUCTOR TO PREVENT FLICKER

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Increased use of motors and other industrial loads on rural lines has, on some systems, introduced flicker problems. The solution to the problem of flicker presented in this bulletin employs a set of nomograms to determine the proper size of secondary or service conductor to be used when the load and service transformer specifications as well as the length of secondary or service circuits are known.

The following considerations should be taken into account in using the attached charts:

1. The values obtained from the charts are valid provided the primary regulation is sufficient to take care of the starting current. In cases where primary regulation is poor other corrective measures may have to be applied.

2. Since in some cases the method outlined here would require the use of service conductors or transformers of larger sizes than is usual in REA usage, some judgment should be used in its application. It should be applied only where motor loads are coincident with lighting demands.

3. When a current-limiting starting device is used, the value of starting current used in the calculations should be the value as limited by the starting device. Tables of average starting currents and starting power factors of various types of motors are included in this bulletin. The tables contain average values as listed by several motor manufacturers and are useful when more precise data are not available.

USE OF THE CHARTS

The following information must be on hand before the secondary size can be determined from the charts:

1. Number of starts per hour, minute, or second, of the motor.

2. Make and size of distribution transformer to be used.

3. The supply voltage (E) on the secondary or service.

4. The starting current (I) of the motor.

5. Power factor of the motor at starting (cos θ)

6. Length of secondary or service circuit (L)

The general procedure is then as follows:

1. Determine the allowable percent of voltage fluctuation from Chart I.

2. Determine the percent R and percent X of the transformer from Table III.

3. Convert the allowable percent voltage fluctuation to allowable percent of transformer and secondary impedance drop by use of Chart II.

4. Determine the percent voltage drop in the transformer and the percent resistance drop in the secondary or service conductor from Chart III.

5. Obtain the required conductor size or resistance in ohms per 1000 feet from Chart IV.

Detailed steps and examples are given in the following pages.

TABLE I

AVERAGE STARTING CURRENTS OF MOTORS

Type of Motor	HP	Voltage (Line to Line)	Starting Current (amps)
Single Phase			
Condenser Start	1/6	110	22
	1/4		23
	1/3		23
	1/3	220	12
	1/2		16
	3/4		23
	1		30
Single Phase			
Split Phase	1/8	110	17
	1/6		28
	1/4		29
	1/3		30
	1/2		37
	3/4		60
Single Phase			
Repulsion-Induction	1/8	110	13
	1/6		13
	1/4		14
	1/3		19
	1/2		26
	3/4		38
	1/2	220	14
	3/4		20
	1		25
	1 1/2		34
	2		41
	3		58
	5		95
	7 1/2		150

TABLE I (continued)

AVERAGE STARTING CURRENTS OF MOTORS

Type of Motor	HP	Voltage (Line to Line)	Starting Current (amps)
Polyphase			
Induction (Squirrel Cage)	1/2	110	19
	3/4		29
	1		41
	1 1/2		58
	2		72
	3		105
	5		165
	7 1/2		235
	10		300
	15		415
	20		490
	25		660
	30		775
	40		1110
	50		1370
	60		1650
	75		2010
	100		2940
	125		3380
	150		4610
	200		6580
	250		7300
	3	208	57
	5		88
	7 1/2		115
	10		155
	15		225
	20		285
	25		360
	30		410
	40		530
	50		715
	1/8	220	3.7
	1/6		4.6
	1/4		6.4
	1/3		9.6
	1/2		10
	3/4		15
	1		21
	1-1/2		31
	2		38

TABLE I (continued)

AVERAGE STARTING CURRENTS OF MOTORS

Type of Motor	HP	Voltage (Line to Line)	Starting Current (amps)
Polyphase	3	220	52
	5		82
Induction	7-1/2		120
(Squirrel Cage)	10		150
	15		220
	20		275
	25		355
	30		415
	40		555
	50		690
	60		865
	75		1050
	100		1500
	125		1800
	150		2390
	200		3290
	250		3650
	1/2	440	4.8
	3/4		7.1
	1		10
	1 1/2		15
	2		18
	3		25
	5		41
	7 1/2		57
	10		74
	15		105
	20		130
	25		165
	30		190
	40		275
	50		345
	60		410
	75		500
	100		735
	125		845
	150		1155
	200		1635
	250		1825
	1/2	550	3.8
	3/4		5.7
	1		7.9
	1 1/2		13

TABLE I (continued)

AVERAGE STARTING CURRENTS OF MOTORS

Type of Motor	HP	Voltage (Line to Line)	Starting Current (amps)
Polyphase	2	550	15
	3		20
Induction	5		36
(Squirrel Cage)	7 1/2		46
	10		59
	15		84
	20		105
	25		135
	30		155
	40		220
	50		290
	60		340
	75		395
	100		590
	125		675
	150		920
	200		1320
	250		1460
	30	2200	40
	40		55
	50		68
	60		95
	75		110
	100		150
	125		195
	150		255
	200		295
	250		365
	300		475

TABLE II

AVERAGE STARTING POWER FACTOR OF MOTORS

Type of Motor	Average Starting Power Factor ($\cos \theta$)
Single Phase	
Capacitor Start	0.85
Split Phase	0.75
Repulsion-Induction	0.65
Three Phase - Squirrel Cage	
Over 3 HP:	
(a) Normal Torque	0.35
(b) High Torque	0.60
(c) High Slip	0.65
Under 3 HP	0.40

TABLE III

PERCENT RESISTANCE AND PERCENT REACTANCE

OF

DISTRIBUTION TRANSFORMERS*

TRANSFORMER RATING (KVA)	ALLIS CHALMERS		GENERAL ELECTRIC		KUHLMAN		LINE MATERIAL		MOLONEY		STANDARD		WAGNER		WESTING-HOUSE	
	% R_T	% X_T	% R_T	% X_T	% R_T	% X_T	% R_T	% X_T	% R_T	% X_T	% R_T	% X_T	% R_T	% X_T	% R_T	% X_T
1.5	2.37	2.08	2.67	2.11	2.60	1.46	2.80	1.33	2.73	1.67	2.60	1.31	2.25	1.31	2.78	1.15
3	2.08	2.04	2.33	2.50	2.16	1.56	2.53	1.61	2.40	1.80	2.27	1.80	2.26	1.80	2.47	1.52
5	2.25	1.79	2.30	2.08	2.16	1.44	2.30	1.93	2.42	2.10	2.20	1.90	2.20	1.99	2.22	1.30
7.5	2.00	2.21	2.15	1.64	2.27	1.60	2.08	2.02	2.27	2.34	2.15	1.80	1.81	1.69	2.06	1.55
10	1.85	2.25	2.00	1.96	1.90	1.84	2.00	2.10	2.02	2.26	2.00	1.90	1.83	2.11	1.79	1.75
15	1.53	2.24	1.72	2.21	1.78	2.52	1.65	2.39	1.82	2.87	1.72	2.20	1.65	2.29	1.58	1.80
25	1.42	2.57	1.51	2.36	1.47	2.40	1,47	2.50	1.53	3.14	1.51	2.40	1.36	2.88	1.60	2.28
37.5	1.32	2.79	1.31	2.47	1.33	3.58	1.27	2.61	1.35	2.90	1.31	2.50	1.20	2.88	1.38	2.68
50	1.16	2.91	1.22	2.52	1.04	3.60	1.23	2.62	1.38	2.96	1.22	2.50	1.08	3.30	1.34	2.44
75	1.09	2.64	1.10	4.47	1.25	3.36	1.15	4.46	1.31	3.10	1.10	3.10	1.16	3.44	1.20	3.40
100	1.13	3.07	1.12	4.46	1.23	3.46	1.13	4.46	1.24	3.10	1.10	3.20	1.07	4.41	1.20	3.70

* Rating from 1.5 KVA to 15 KVA inclusive are REA type. Rating of 25 KVA and above are conventional double bushing type.

Values of R_T and X_T are from manufacturers' data as of January 1942.

ALLOWABLE PERCENT OF VOLTAGE FLUCTUATION

This chart shows the permissible percent of voltage fluctuation for a varying number of fluctuations (or motor starts) per unit time.

Example: A three phase $7\frac{1}{2}$ H.P. 220 Volt motor starts 6 times per hour.

Against 6 fluctuations per hour on the curve read 3.6% allowable voltage fluctuation.

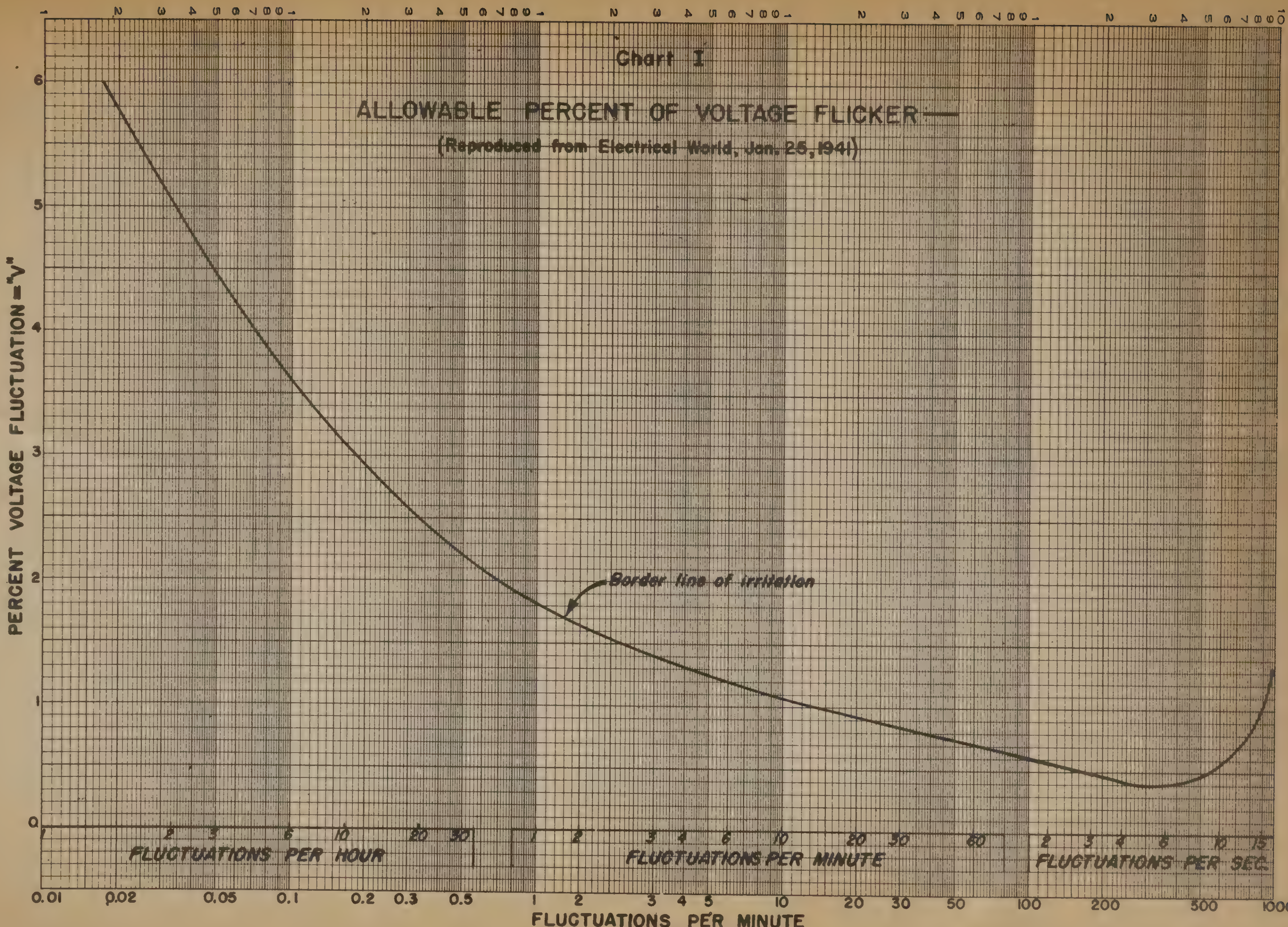


Chart I
ALLOWABLE PERCENT OF VOLTAGE FLICKER —
(Reproduced from Electrical World, Jan. 25, 1941)
Border line of irritation
PERCENT VOLTAGE FLUCTUATION = "V"
FLUCTUATIONS PER HOUR
FLUCTUATIONS PER MINUTE
FLUCTUATIONS PER SEC.
FLUCTUATIONS PER MINUTE

CHART II

For Conversion of Allowable Percent Voltage Fluctuation to Allowable Percent of Transformer and Secondary Impedance Drop.

Equation of nomogram: $Z = \frac{1000WV}{IE}$

Z = Allowable percent of transformer and secondary impedance drop

W = Transformer KVA per phase

V = Allowable percent voltage fluctuation

I = Starting Current

E = Rated secondary voltage, phase to neutral

1. Use value of V obtained from Chart I.
2. Connect V and W. Mark intersection on A.
3. Proceed from A to E. Mark intersection on B.
4. Connect B and I. Intersection on Z is allowable percent voltage fluctuation under actual bad conditions.

Example: 3 - 3KVA Kuhlman transformers are used to serve the motor in the previous example. The starting current (from Table I) is 120 amps. Assume that the starter used limits the starting current to 35% of this value. Then, I = 42 amps.

1. Connect V = 3.6% with W = 3 KVA per phase. Mark intersection on A.
2. Proceed from A to E = 220/1.73 = 127 volts phase to neutral. Mark intersection on B.
3. Connect B and I = 42 amps. Then Z = 2%.

CHART II

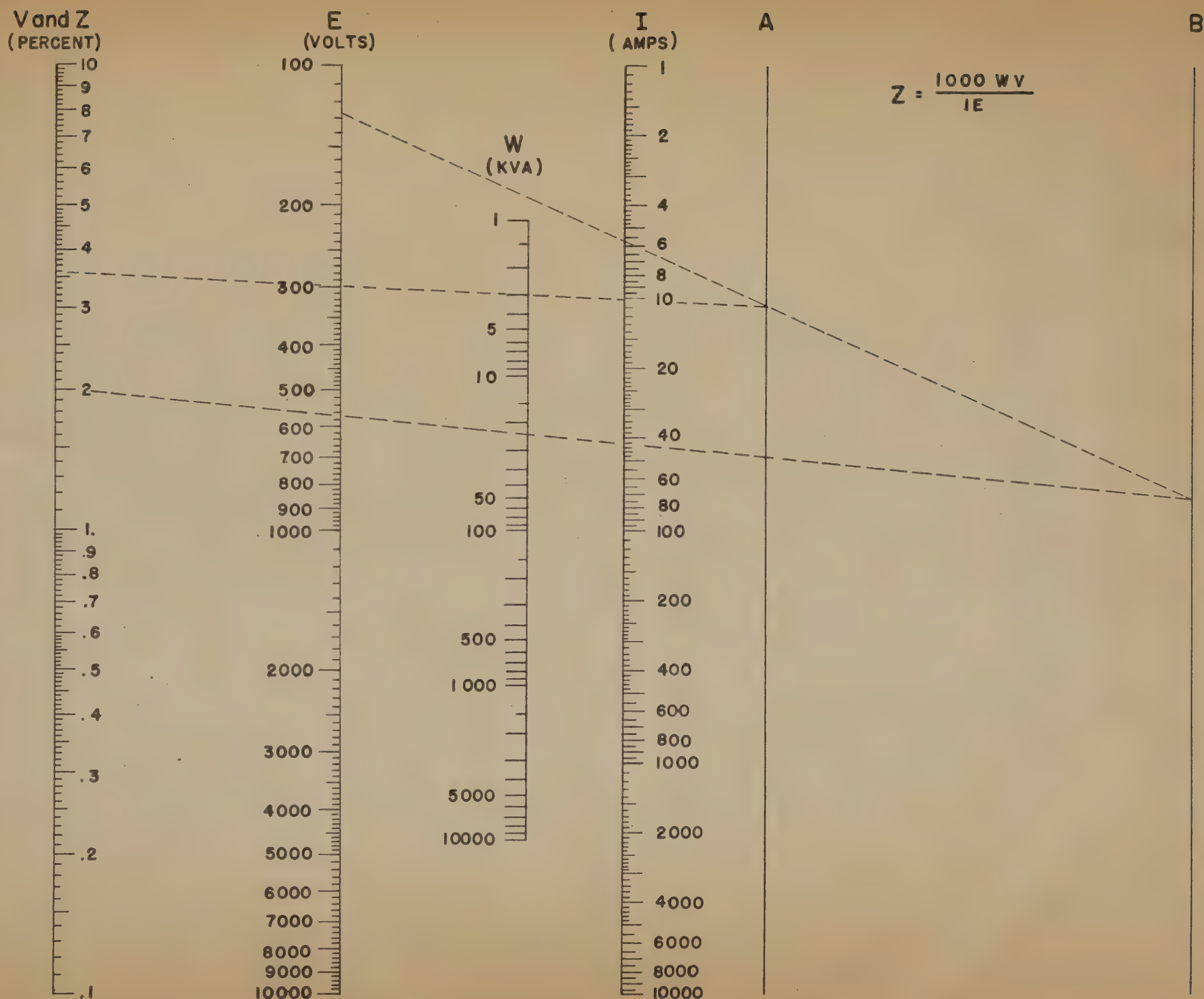

V and Z
(PERCENT)
E
(VOLTS)
W
(KVA)
I
(AMPS)
A
B
$Z = \frac{1000\ WV}{IE}$
10
9
8
7
6
5
4
3
2
1.
.9
.8
.7
.6
.5
.4
.3
.2
.1
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
1
5
10
50
100
500
1 000
5000
10000
1
2
4
6
8
10
20
40
60
80
100
200
400
600
800
1000
2000
4000
6000
8000
10000

CHART III

(a) <u>To Determine Percent Voltage Drop in Transformer</u>

1. Use values of R_T and X_T from Table III.
2. Connect R_T and Power Factor. Read value of intersection on C.
3. Connect X_T and Power Factor. Read value of intersection on D.
4. Percent impedance drop in transformer: $Z_T = C + D$.
5. Percent resistance drop in secondary conductor:

   $Z_s = Z - Z_T$

(b) <u>To Determine Percent Resistance Drop in Secondary or Service Conductor Circuit.</u>

1. Connect Z_s and Power Factor
2. Intersection on R_s is percent resistance drop in secondary or service circuit.

Example: (a) From Table III, for the transformer in the previous example, $R_T = 2.16\%$, $X_T = 1.56\%$. Starting power factor for the motor, from Table II, is 0.35.

1. Connect $R_T = 2.16\%$ and Power Factor $= 0.35$. Read 0.7% on C.
2. Connect $X_T = 1.56$ and Power Factor $= 0.35$. Read 1% on D.
3. $ZT = C + D = 1 + 0.7 = 1.7\%$
4. $Z_s = Z - Z_T = 2 - 1.7 = 0.3\%$
   (Z obtained from previous example in Chart II)

(b)

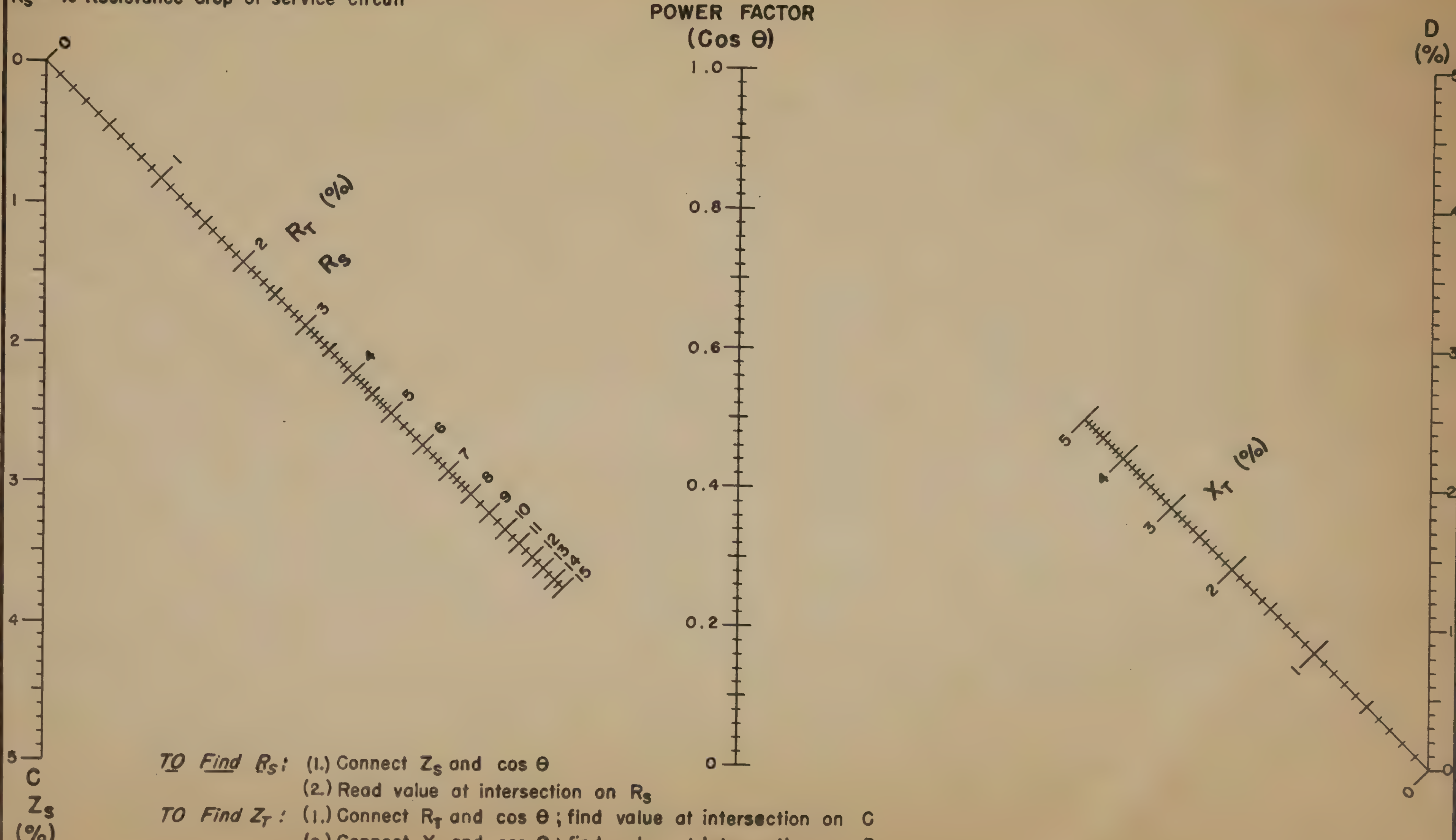
1. Connect $Z_s = 0.3\%$ and Power Factor $= 0.35$. Read $R_s = 0.9\%$

R_T = % Resistance of transformer
X_T = % Reactance of transformer
θ = Power factor angle of motor at starting
Z_T = % Regulation of transformer
Z_S = % Regulation of service circuit
R_S = % Resistance drop of service circuit

Chart III

EQUATIONS of CHART

1. $C = R_T \cos \theta$
   $D = X_T \sin \theta$
   $Z_T = C + D$
2. $Z_S = R_S \cos \theta$



TO Find R_S: (1.) Connect Z_S and $\cos \theta$
(2.) Read value at intersection on R_S

TO Find Z_T: (1.) Connect R_T and $\cos \theta$; find value at intersection on C
(2.) Connect X_T and $\cos \theta$; find value at intersection on D
(3.) $Z_T = C + D$

CHART IV

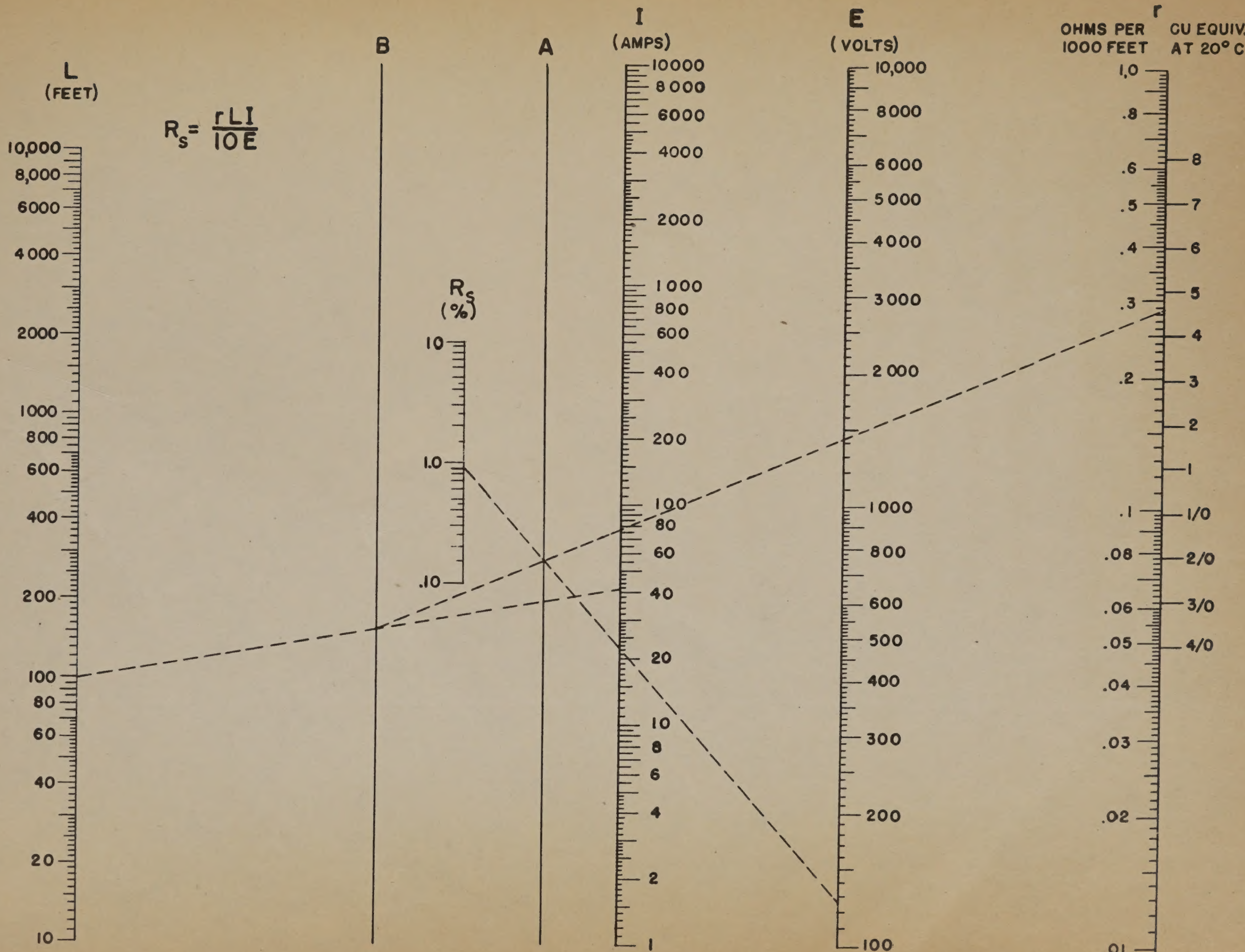
TO DETERMINE SECONDARY OR SERVICE CONDUCTOR SIZE

1. Connect R_s and E. Mark intersection on A.
2. Connect L and I. Mark intersection on B.
3. Connect B and A. Mark intersection on "r".
4. Intersection on "r" shows resistance of conductor in ohms per 1000 ft. or copper equivalent.

Example: Length of service L = 100 feet.

1. Connect R_s = 0.9% and E = 127 volts. Mark intersection on A.
2. Connect L = 100 feet and I = 42 amps. Mark intersection on B.
3. Connect points on A and B. Intersection on r = 0.275 ohms/1000 feet., or No. 4 copper equivalent can be used.

CHART IV



L
(FEET)
$R_s = \frac{rLI}{10E}$
B
A
I
(AMPS)
E
(VOLTS)
r
OHMS PER 1000 FEET
CU EQUIV. AT 20° C
R_s (%)
10,000
8,000
6000
4000
2000
1000
800
600
400
200
100
80
60
40
20
10
10000
8000
6000
4000
2000
1000
800
600
400
200
100
80
60
40
20
10
8
6
4
2
1
10
1.0
.10
10,000
8000
6000
5000
4000
3000
2000
1000
800
600
500
400
300
200
100
1,0
.8
.6
.5
.4
.3
.2
.1
.08
.06
.05
.04
.03
.02
.01
8
7
6
5
4
3
2
1
1/0
2/0
3/0
4/0